

Dynamical Casimir Effect

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What happens if you place two mirrors facing each other in empty space? The naïve answer is nothing at all.

Surprisingly, both mirrors attract each other due to the presence of the electromagnetic vacuum (Fig. 1). This phenomenon, now called the Casimir effect, was predicted in 1948 by the Dutch theoretical physicist Hendrik Casimir, and has been recently measured at the 15% accuracy level using cantilevers. A force of similar nature between a conducting plane and a conducting sphere has also been measured with increasing precision using torsion balances, atomic force microscopes, and micromechanical resonators. Casimir forces are relevant for nanotechnology because they affect the operation of microelectromechanical systems. Also, the predicted existence of new interactions with coupling comparable to gravity but range in the micrometer range adds strong motivations to control the Casimir force at the highest level of accuracy.

When the Casimir plates are put in non-uniform accelerated motion, it is in principle possible to create real photons out of vacuum. This effect is referred to in the literature as dynamical Casimir effect, or motion-induced radiation. The most favorable setup for observing it is a high quality microwave cavity where one of its mirrors is oscillating with one of the resonant frequencies of the cavity. In such a case, the number of photons inside the cavity accumulates slowly and grows exponentially in time. Unfortunately, unlike

the static Casimir effect, an experimental verification of the dynamical counterpart is still lacking. The main reason is that typical resonance frequencies for microwave cavities are of the order of gigahertz, and it is of course very difficult to make a mirror oscillate at such high frequencies. At present, alternative ideas are being pursued, such as switching an effective mirror on and off at very short intervals of time, changing the reflectivity of a semiconductor layer inside the cavity by shining a pulsed laser beam on its surface.

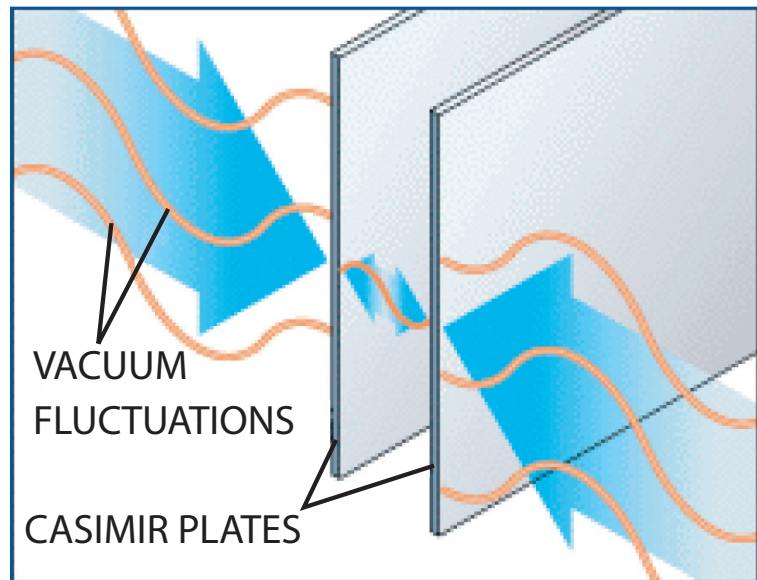


Figure 1—
When two uncharged, perfectly conducting parallel plates are facing each other, they modify the mode structure of the electromagnetic vacuum. As a result, there is a net attractive force between them, the so-called Casimir force.

We have studied the creation of photons in 3D oscillating microwave cavities. The physical degrees of freedom of the electromagnetic field are expressed in terms of two independent scalar fields, the so-called Hertz potentials [1]. One of them corresponds to transverse electric (TE) modes, satisfying Dirichlet boundary conditions on the moving mirror, while the other one corresponds to transverse magnetic (TM) modes and verifies (generalized) Neumann boundary conditions. The rate of photo-production for the TM photons is in general larger than for TE photons. We have also studied transverse electromagnetic (TEM) modes, that appear in non-simply connected cavities, such as between two concentric hollow cylinders. This case reduces to a 1D problem for a scalar field with time-dependent boundary conditions (Fig. 2).

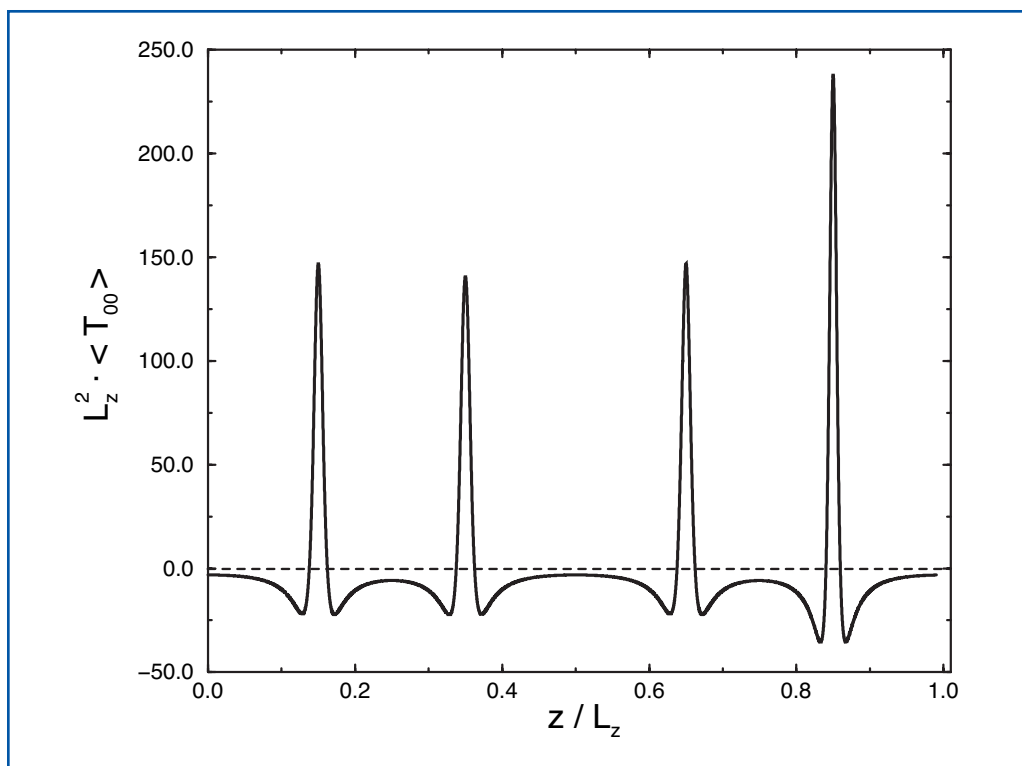


Figure 2—
Energy density profile for a 1D cavity whose length oscillates at the fourth resonant frequency of the static cavity. Real photons are generated inside the cavity, with a structure of four peaks that move back and forth within the cavity. The total energy inside the cavity increases exponentially in time at the expense of the energy supplied to the mirrors to keep them oscillating.

Finally, we have started the theoretical modeling of a proposed experiment to measure the dynamical Casimir effect with the semiconductor of time-dependent reflectivity. We have shown that the proposed setup offers several advantages over the case of motion-induced radiation arising from moving mirrors, such as much faster photo-production rates and milder fine tuning problems [2].

[1] M. Crocce, D.A.R. Dalvit, F.C. Lombardo, and F.D. Mazzitelli, "Hertz Potentials Approach to the Dynamical Casimir Effect in Cylindrical Cavities of Arbitrary Section," to appear in *Journal Opt. B* (2005); quant-ph/0411106.

[2] M. Crocce, D.A.R. Dalvit, F.C. Lombardo, and F.D. Mazzitelli, "Model for Resonant Photon Creation in a Cavity with Time-Dependent Conductivity," *Phys. Rev. A* **70**, 033811 (2004).

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